GROWTH RESPONSES OF HEMP TO DIFFERENTIAL SOIL AND AIR TEMPERATURES

CLARENCE H. NELSON

(WITH THREE FIGURES)

Introduction

Recent studies of physiological ontogeny in plants have revealed a number of significant interrelationships among different plant organs. Considerable knowledge of the formative effect of one organ upon another during the course of development has been obtained by exposing various parts of the plant to contrasted environmental conditions such as differences in photoperiod or temperature. In studies of this kind, however, observations have usually been confined to responses of the shoot with only incidental attention to the root. Though the effect of temperature upon development has been repeatedly studied, entire plants have commonly been exposed to different temperatures in such a manner that it has been difficult, if not impossible, to determine whether variations in formative response were primarily due to the effect of a given temperature upon the root or upon the shoot. In order to determine whether a given temperature exerted its characteristic formative and metabolic effects primarily through the root or through the shoot, a growth experiment employing a rapidly developing annual with tops and roots exposed to unlike temperatures was devised. Ordinary hemp, *Cannabis sativa,* was selected as test material, not only because of its experimental convenience and known sensitivity to temperature, but because of current interest in its response to the low temperatures of the northern latitudes in which commercial hemp production is at present being developed. A record of structural development was maintained from the time of germination to maturity, and the various formative responses were correlated with salt and water intake.

Procedure

The experiment consisted of two parts, performed sequentially. In the first part (A), employing an unselected strain of the native hemp, *Cannabis sativa,* the course of structural development, water, and salt intake was traced in a population comprising both sexes in the usual proportions. In the second portion of the experiment (B), employing a selected strain of commercial Kentucky hemp, plants were studied individually in order to observe nutritional as well as structural differences distinguishing staminate and pistillate individuals. Apart from differences in number of plants per culture and in variety of hemp used, experimental conditions were essentially comparable in both portions of the experiment.

In part (A) of the experiment, seedlings of native Iowa hemp were transplanted from sand flats 11 days after germination to two-gallon glazed jars each containing two kilograms of acid-washed, solute-free quartz gravel of $\frac{1}{8}$- to $\frac{1}{4}$-inch size. Three plants were placed in each of 72 jars to which had been added (through $\frac{5}{8}''$ pyrex glass tubes extending to the bottom) three liters of 0.01 per cent. concentration of WITHROW's nutrient solution for moderate light (**22**). A division into four different temperature series of 18 jars each was then made as follows:

1. Top and root both maintained at 30° C., designated as H/H.
2. Top temperature at 30°, root temperature at 15° C., designated as H/L.
3. Top temperature at 15°, root temperature at 30° C., designated as L/H.
4. Top and root both maintained at 15° C., designated as L/L.

To avoid undue shock to the young seedlings, the above temperature differentials were achieved gradually during the first four days after transplantation.

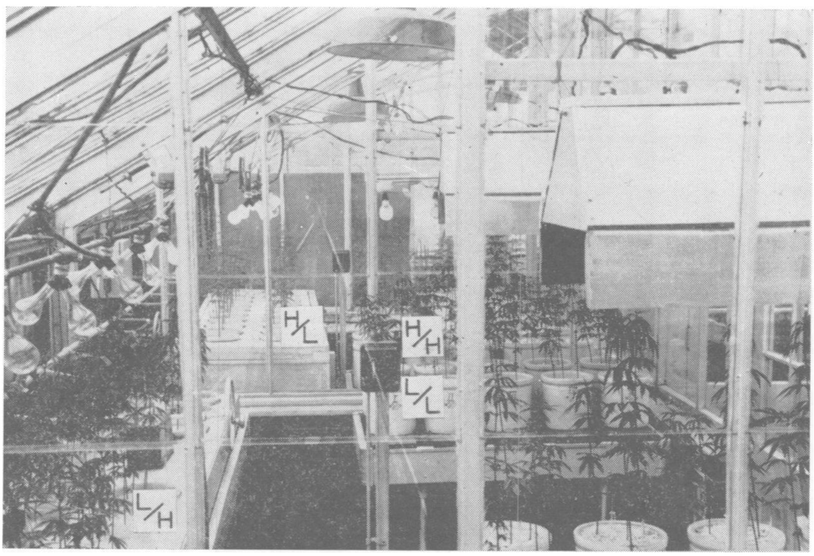

FIG. 1. Experimental set-up showing: (a), H/H series; (b), H/L series; (c), L/H series; (d), L/L series.

The H/H and H/L groups were placed in a greenhouse room whose air temperature was kept at 30° C. by thermostatically controlled steam heat. To obtain a low root temperature for the H/L plants, their jars were encased in a specially designed insulated bench (fig. 1), the temperature inside of which was thermostatically maintained at 15° C. by means of a Frigidaire compressor unit. The 15° differential in temperature thus occurred at the ground line or transition point from plant root to top.

The L/H and L/L groups were placed in an adjoining cold room whose air temperature was maintained at 15° C. by means of thermostatically regulated heat. The L/H jars were encased in an electrically heated, insulated bench (fig. 1), the temperature inside of which was maintained at 30° C. by thermostatic control.

TABLE I

MEAN DAILY WATER CONSUMPTION BY TWO SETS OF HEMP PLANTS (A) AND (B) DURING GROWTH AT DIFFERENT ROOT AND SHOOT TEMPERATURES

(A) 1942	Mean water consumption per plant per day				(B)† 1943	Mean water consumption per plant per day			
From to	H/H	H/L	L/H	L/L	From to	H/H	H/L	L/H	L/L
	ml.	*ml.*	*ml.*	*ml.*		*ml.*	*ml.*	*ml.*	*ml.*
10/22–10/26	8.0	7.5	10.6	9.8	1/31–2/5	30.0	24.2	19.9	8.1
10/26–10/31	10.2	5.7	11.1	6.2	2/5 –2/12	20.4	12.9	29.1	14.5
10/31–11/5	18.1	12.3	9.9	6.6	2/12–2/19	40.9	18.6	26.2	16.8
11/5 –11/7	17.7	9.1	14.7	9.5	2/19–2/26	54.4	32.9	38.0	24.8
11/7 –11/14	23.4	14.7	15.7	12.7	2/26–3/5	92.9	55.7	51.6	35.5
11/14–11/20	21.7	16.3	17.5	17.3	3/5 –3/10	79.1	56.8	59.1	37.3
11/20–11/24	24.6*	11.3	23.8	14.2	3/10–3/16	101.9	64.1	72.3	62.2
11/24–11/27	20.0	13.7*	28.4	18.9	3/16–3/22	92.0	68.6	83.3	63.0
11/27–12/3	25.0	17.2	19.7	9.9	3/22–3/27	105.1	75.3	79.8	74.8
12/3 –12/8	19.2	17.3	21.8*	13.6*	3/27–4/2	103.9	75.8	113.9	98.2
12/8 –12/12	21.5	8.7	13.0	10.4	4/2 –4/8	124.9*	79.1	86.7	70.3
12/12–12/20	23.4	15.3	17.7	13.4	4/8 –4/15	97.0	66.2*	82.2	63.5
12/20–12/28	21.0	15.8	13.1	6.0	4/15–4/22	110.4	66.5	85.0	72.3
12/28–1/4/43	22.2	15.3	15.2	6.8	4/22–4/29	103.4	69.8	83.2*	76.3*
Total water consumption per plant, mean	1472	968	1196	809	Total water consumption per plant, mean	7465	4774	5678	4489

* Anthesis week.
† Data of (B) above shown for separate staminate and pistillate plants in figure 2 and in table III.

Temperatures were checked continuously by means of thermographs placed inside the insulated benches and in the two rooms to provide a constant 15° temperature differential. Slight diurnal air temperature variations of brief duration were inevitable but a minimum 15° differential was nevertheless maintained at all times. A hydrograph placed in each room provided continuous records of relative humidity. The air in the two rooms was maintained at a mean relative humidity of 50 per cent. by daily spraying of the concrete floors with water as needed.

The culture jars were completely drained twice weekly by siphoning and the quantity of residual solution was measured to provide an exact record of water consumption throughout the growth cycle (table I). To maintain the optimum nutrient supply it was necessary to replenish each jar with two liters of nutrient solution following drainage of residues. As growth pro-

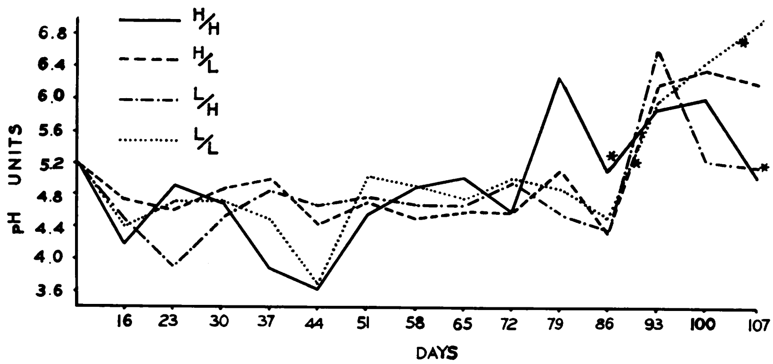

FIG. 2. pH of weekly nutrient residues. Average pH of fresh nutrient solution added was 5.2. * Date of anthesis.

gressed the concentration of the nutrient solution used was gradually increased to 0.02 per cent. In order to trace the general effect of roots on the hydrion concentration of the nutrient solution, the pH of the original stock solution and of the residues recovered at the time of renewal each week were measured electrometrically by means of a glass electrode (fig. 2).

To provide a photoperiod favorable to vigorous vegetative development of the plants, the extremely short day length of this season of the year (October–January) was augmented by seven hours of daily supplemental illumination of approximately 300 fc intensity at pot level supplied by an automatically controlled battery of Mazda bulbs. This insured a daily 16-hour photoperiod. The supplemental lighting was also provided during the daytime whenever the sky was overcast. A record of the sex of each plant in part (A) was made at the expiration of 82 days. The supplemental lighting was then discontinued and at the end of the 99th day (following 17 days of approximately 8-hour photoperiod provided by natural December daylight alone) another plant sex check was made to determine final sex ratios and percentage of sex-reversal in each of the four temperature series (table II).

Continuous observation of leaf growth was made, a weekly leaf count and a daily record of leaf abscission was kept (table II). Leaf areas were determined by making blueprints of all the leaves from six typical plants, including approximately an equal number of each sex, in each of the four temperature series. The areas of the blueprint impressions were subsequently computed by use of a planimeter and the data recorded as mean area per leaf in each series (table II). Stem elongation was measured weekly and a comparison of stem diameters and internodal lengths was made at the end of the experiment (table II).

TABLE II

MORPHOLOGY OF HEMP PLANTS IN FOUR TEMPERATURE SERIES OF PART (A); 54 PLANTS IN EACH SERIES, AGE 99 DAYS

	H/H	H/L	L/H	L/L
LEAVES				
Total number of leaves per plant	50	41	65	48
Leaves abscissed in 99 days	14	12	8	10
Intact leaves per mature plant	36	29	57	38
Mean area per leaf ($cm.^2$)	5.5	5.7	10.4	10.7
STEMS				
Diameter at basal node, mm.	2.7	2.7	3.4	3.1
Height in centimeters	60	57	47	49
Number of nodes produced	31	28	16	18
Internodal length, cm.	1.9	2.0	2.9	2.8
SEX RATIOS				
Percentage male plants, 82nd day, 16-hr. photoperiod	50.0	41.5	4.2	3.8
Percentage female plants, 82nd day, 16-hr. photoperiod	50.0	58.5	95.8	96.2
Percentage male plants, 99th day, photoperiod shortened to 8 hrs. during last 17 days	64.0	56.5	52.0	45.5
Percentage female plants, 99th day, photoperiod shortened to 8 hrs. last 17 days	36.0	43.5	48.0	54.5
Percentage sex reversals, male to female between 82nd and 99th days	9.5	0.0	0.0	0.0
Percentage sex reversals, female to male between 82nd and 99th days	24.0	15.0	48.0	41.5

As a check on growth responses observed in the first portion of the experiment (part A), described above, and in order to obtain comparative data on a commercial variety of hemp improved by selection, Kentucky hemp was employed in the second part (B) of the experiment. As stated, in this second experiment cultures of one plant per jar were employed in order that weight, ash, and water requirements could be correlated with the sex of each plant. Seeds of Kentucky hemp for this portion (B) of the experiment were planted January 15, transplanted January 27, and subsequently exposed to temperature variables and otherwise treated as in (A). Four replicate samples comprising six plants, three of each sex, from each temperature series were comminuted and dried to constant weight at 105° C.

These samples were then ignited at low red heat and the ash weighed to constant weight.

Data and discussion

Plants in all four temperature series developed rather uniformly for the first four weeks, after which differences in growth began to be apparent. Variations in stem elongation, stem diameter, leaf size, texture, thickness, and color had become quite marked by the seventh week. Mean daily water consumption per plant increased progressively until anthesis at which time a sharp decline was noted in all series (tables I and III; fig. 3). In each instance a subsequent increase in water absorption occurred at the late flowering and seed formation stage. Coincident with reduced water intake a marked upward shift in pH of weekly nutrient residues was noted (fig. 2).

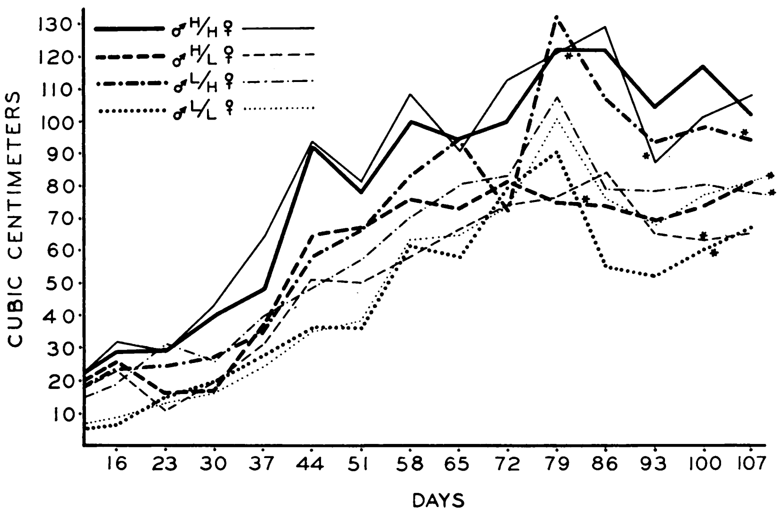

FIG. 3. Daily water intake of male and female hemp plants (B) during growth cycle. * Date of anthesis.

H/H SERIES

At the seventh week of growth the mean stem length of plants in this series had surpassed all others by more than seven centimeters. These plants exhibited the greatest stem length and node number but smallest internodal length and stem diameter until maturity (tables II and IV). Though the smallest mean leaf area occurred in this series (table II), plants of this group possessed the highest percentage of leaf ash (table V). It is also noteworthy that the H/H plants absorbed the greatest total quantity of water in their growth cycle in spite of their relatively small aggregate leaf area. The water absorption per unit dry weight of the entire plant (water requirement) was not only greatest in this series but it surpassed the two cold air temperature series (L/H and L/L) by more than two and one-half times (table VI). The water loss in milliliters per square centimeter of leaf area was more than twice that of the L/L series. This would suggest that

TABLE III

MEAN DAILY WATER CONSUMPTION BY STAMINATE AND PISTILLATE HEMP PLANTS (B) AT DIFFERENT ROOT AND SHOOT TEMPERATURES

1943	MEAN WATER CONSUMPTION PER PLANT PER DAY							
FROM TO	H/H		H/L		L/H		L/L	
	♂	♀	♂	♀	♂	♀	♂	♀
	ml.	*ml.*	*ml.*	*ml.*	*ml.*	*ml.*	*ml.*	*ml.*
1/31–2/5	29	32	26	23	23	19	7	9
2/5 –2/12	29	29	16	11	24	31	15	13
2/12–2/19	40	43	17	19	27	26	19	16
2/19–2/26	48	64	37	31	35	39	28	24
2/26–3/5	92	94	65	51	58	49	36	35
3/5 –3/10	78	81	67	50	66	57	36	38
3/10–3/16	100	108	76	58	83	70	61	63
3/16–3/22	94	90	73	66	94	80	58	65
3/22–3/27	100	113	81	73	72	83	79	73
3/27–4/2	122	121	75	76	132	107	90	101
4/2 –4/8	122*	120	74*	84	107	79	55	76
4/8 –4/15	104	87	69	65	93	78	52	68
4/15–4/22	117	101*	74	63	98	80	61	77
4/22–4/29	101	107	80	65*	94	78	66*	80
					....	....	....	....
					...........*	...........*	....	...........*
Total water consumption per plant, mean	7452	7540	5182	4577	6290	5456	4109	4628

* Anthesis week.

TABLE IV

SEX DIFFERENCES OF FOUR TEMPERATURE SERIES OF HEMP PLANTS (B). AGE 106 DAYS

	H/H		H/L		L/H		L/L	
	♂	♀	♂	♀	♂	♀	♂	♀
No. of leaves per plant (mean)	34	71	31	51	41	52	39	40
No. of nodes per plant (mean)	36	28	34	26	20	15	22	16
Height of plant in cm. (mean)	97	79	87	69	66	56	67	57
Basal stem diameter in mm. (mean)	2.53	2.89	2.55	2.97	3.29	3.49	3.05	3.14
Dry. wt. per plant in gm. (mean)	6.27	7.03	4.37	7.25	13.87	10.47	8.32	10.16
Age of plants in days at anthesis (median)	80	93	82	99	106	112	101	112
Sex ratios (%)	60	40	33	67	27	73	27	73
Total water consumption per plant (ml.)	7452	7540	5182	4577	6290	5456	4109	4628
Water requirement* ...	1188	1073	1186	631	454	520	493	456

* Water requirement computed as total ml. water consumed by plant divided by total grams dry weight of plant.

rate of water absorption and transpiration may not be so much a direct function of aggregate leaf area per plant as of soil and air temperature.

Reduced water supply to plants with lowering of the soil temperature was established experimentally by SACHS (**21**). The subsequent works of

TABLE V

ANALYSES OF HEMP PLANTS IN FOUR TEMPERATURE SERIES (B). MEANS FOR SIX PLANTS IN EACH SERIES, AGE 106 DAYS

TEMPERATURE SERIES	FRESH WEIGHT	DRY WEIGHT	PERCENTAGE DRY WT.	ASH WEIGHT	ASH, PERCENTAGE DRY WT.
	gm.	*gm.*	%	*mg.*	%
			LEAVES		
H/H	4.11	0.89	21.70	114.1	12.80
H/L	3.75	1.01	26.82	94.8	9.40
L/H	9.22	2.45	26.57	207.3	8.48
L/L	8.24	2.21	26.81	202.0	9.14
			UPPER STEM		
H/H	4.56	1.25	27.49	79.6	6.35
H/L	3.42	1.00	29.34	74.1	7.39
L/H	6.23	1.82	29.19	86.2	4.74
L/L	6.35	1.73	27.18	97.6	5.66
			BASAL STEM		
H/H	8.11	2.96	26.50	80.5	2.72
H/L	4.77	2.09	43.77	48.0	2.08
L/H	12.64	5.04	39.83	129.0	2.53
L/L	8.86	3.41	38.44	91.0	2.67
			ENTIRE TOP		
H/H	16.77	5.11	30.20	274.2	5.38
H/L	11.94	4.10	34.37	216.9	5.29
L/H	28.09	9.30	33.10	422.5	4.59
L/L	23.44	7.34	31.35	390.6	5.33
			ENTIRE ROOT		
H/H	9.53	1.55	16.23	189.2	12.21
H/L	10.66	1.71	16.05	146.5	8.57
L/H	21.39	2.86	13.39	301.2	10.52
L/L	14.55	1.90	13.07	128.2	6.75
			ENTIRE PLANT		
H/H	26.31	6.65	25.25	463.4	6.95
H/L	22.60	5.81	25.70	363.4	6.97
L/H	49.49	12.17	24.60	723.7	5.94
L/L	38.00	9.24	24.32	518.8	5.62

ARNDT (**1**), DEMIDENKO and BARINOVA (**6**), KRAMER (**12, 13, 14**) and MAXIMOV (**16**) essentially agree that soil water viscosity is increased at lowered soil temperature, rendering less water available to plants. Lowered absorbing capacity of the roots is attributed to decreased permeability of root cell walls and protoplasm. These factors, together with retarded physiological activity at low soil temperature, result in slower root growth with the eventual production of a smaller root system. MAXIMOV (**16**) makes a distinction between heat-loving plants and those of the winter-cereal type, the latter being known to grow well in late autumn and early spring in spite of periodical frosts. This is in contrast to the sunflower, a warm-temperature plant (**4**), in which the critical ratio between transpiration and water absorption was reached when the root temperature was lowered to 40° F. (4.5° C.). Amount of wilting increased with further lowering of temperature. DÖRING (**8**), not confining his observations to one kind of plant, found that in 51 different species water absorption decreased from 0.30 to 79.91 per cent. with a drop in soil temperature from 20° to 0° C. Growth was retarded 70 to 90 per cent. in the species showing greatest absorption sensitivity. Seven spe-

TABLE VI

WATER REQUIREMENT AND ANABOLIC EFFICIENCY OF HEMP PLANTS IN FOUR TEMPERATURE SERIES (B). MEAN FOR 15 PLANTS IN EACH SERIES, AGE 106 DAYS

	H/H	H/L	L/H	L/L
Leaf area per plant, sq. cm.	253.3	234.9	275.5	317.5
Total water absorbed per plant, ml.	7465	4774	5678	4489
Total water loss per $cm.^2$ leaf area, ml.	29.5	20.3	20.6	14.1
Mean dry wt. per plant, gm.	6.65	5.81	12.17	9.42
Water requirement*	1120	921	466	486
$\frac{\text{Dry wt., mg.}}{\text{Leaf area, sq. cm.}}$	26	25	44	29
$\frac{\text{Ash wt., mg.}}{\text{Leaf area, sq. cm.}}$	1.8	1.6	2.6	1.6
$\frac{\text{Dry wt.} - \text{Ash (mg.)}}{\text{Leaf area, sq. cm.}}$	24	23	42	28
Top/root ratio, dry wt.	3.30	2.40	3.22	3.86

* Water requirement computed as total water consumed by plant divided by total dry weight of plant.

cies of plants, on the other hand, showed slightly increased absorption under the same conditions.

Percentage dry weight and ash of roots was highest in the H/H series (table V). While the roots of these plants comprised only a small percentage of the fresh weight of the entire plant, their content of organic matter was relatively large. In the H/H male plants, the roots were coarse in texture and relatively unbranched, while roots of female plants were finer in texture and considerably more branched.

High temperature of both soil and air had the effect of abbreviating the life span and of increasing the amount of leaf abscission. These plants showed the earliest inception of anthesis and earliest senescence. Appearance of staminate flowers preceded the pistillate by approximately 11 days. The series as a whole flowered a week earlier than the H/L plants and three weeks earlier than the two low air temperature series. Increasing soil temperature (**23**) from 22° to 34° C. accelerated heading of Marquis wheat by as much as 11 days, but soil temperatures above 34° C. retarded or prevented earing. A preponderance of male hemp plants occurred in the H/H series of both the (A) and (B) groups. In the first group (A), grown from October to January with 16-hour photoperiod for the first 82 days, sex reversals in both directions were noted at the end of 17 days (age 99 days) of eight-hour daylength. Some reversal of male to female was noted but the percentage shift of female to male was two and a half times as great (table II). No hermaphroditism, monoecism or sex reversal was apparent in 106-day-old plants of the (B) group, grown in the January–April portion of the year with 16-hour photoperiod for 80 days followed by 26 days of approximately $12\frac{1}{2}$ hours photoperiod (natural day-length) for the remainder of the growth cycle.

The residual solution of the H/H series in the (B) group reached its lowest acidity at 44 days and attained its maximum pH on the 79th day. The H/H residues showed maximal pH fluctuation (2.6 pH units) and achieved lowest acidity of the nutrient residues of all series (fig. 2).

H/L SERIES

Both the aggregate number of leaves produced and the total leaf area per plant were smaller in this than in any other series. The leaves themselves were relatively thin and more finely veined than in the L/H series. Leaf abscission was nearly as high as in the H/H series (table II). These plants showed least anabolic efficiency as noted by their low fresh and dry weight per plant (table V). CARROLL (**3**) similarly found low soil temperature to be more injurious to turf grass development than low air temperature. The water requirement in male hemp plants was nearly twice that of the female plants in this series (table IV). It is noteworthy that the percentage dry weight of the basal stems in the H/L series was 43.8 per cent., indicating extensive storage of organic materials in the lower stem region. This fact, coupled with a low percentage dry weight of roots, suggests the possibility of impaired translocation of reserves into the region below the ground line due to low root temperatures. Maximal free acidity of nutrient residues drained from the culture jars was not achieved in this series until the 86th day but the maximum pH occurred soon afterwards on the 100th day (fig. 2).

Gardenia plants (**11**), subjected to low root temperature after having grown at high soil temperature, showed little further vegetative growth but set buds. On the other hand, plants that were subjected to high root temperature following growth at low soil temperature grew vigorously but set no buds.

L/H SERIES

Maximum stem diameter and greatest internodal length characterized the plants in this temperature series. The leaves were also unusual in appearance, being very coarse in texture, large in size, extremely thick, and intensely green in color. There was practically no leaf abscission in the L/H series during the first seven weeks and total abscission was lowest of the four series (table II). At 58 days of age these plants were beginning to show more extensive root development than those of the other three series, this characteristic becoming much more pronounced at maturity as confirmed by mean fresh, dry, and ash weights of the entire root of the plants in the (B) group (table V). The L/H plants flowered two weeks later than the H/H series in the (A) group, and the difference in time of flowering was even more pronounced in the second or (B) group. The pH of the nutrient residues was lowest in this series on the 86th day but rose abruptly and achieved its maximum pH on the 93rd day (fig. 2). CANNON (**2**), working with *Opuntia versicolor,* also found relatively great vegetative activity to occur under conditions of low air and higher soil temperature.

L/L SERIES

The leaves on these plants were relatively large, attaining the maximum area per leaf of the four series (table II). Though the stems attained a height only slightly greater than in the L/H plants, the stem diameter was relatively large. Leaf abscission was next to the lowest of the four temperature series. Despite the large leaves and maximal aggregate leaf area per plant, this series absorbed the smallest quantity of water during its growth period (table VI). These plants showed highest absolute ash weight in the upper stem but a low percentage of ash indicating considerable storage of organic material in the stem (table V). This series also had the lowest percentage root dry weight (table V). The root dry and ash weight percentages were lowest in this series (table VII). In view of the relatively large fresh weight, these roots contained a high percentage of water. In the L/L series, lowest pH of nutrient residue occurred at the 84th day while maximum pH was recorded on the 107th day (fig. 2). L/L plants flowered three weeks later than the H/H series and produced a preponderance of pistillate flowers in both the (A) and (B) groups. In Marquis wheat (**23**) greatest dry weights of tops and roots resulted in plants grown at a soil temperature of 22° C. Leaves were largest at 22° and became lighter in color as the soil temperature rose above 32° C.

Though the high frequency of sex reversal occurring in the (A) group (table II) was not duplicated by the (B) group (table IV), the general low air temperatures of the L/H and L/L series nevertheless predisposed to pistillate flowers. MOLLIARD (**17**) using *Mercurialis annua* also found a marked correlation between the growth temperatures employed and sex ratios of the plants. *Poa pratensis* (**5**) at soil temperature of 15° C. was found to grow tall, succulent, and bushy with many leaves; at 35° C. soil temperature the plants were erect, non-succulent, with few leaves, and short in stature. The vegetative habit of hemp in the L/L series was essentially similar to the former except as to stem length while the H/H series showed many of the same characteristics as the above grass grown at 35° root temperature. Hemp differed from the grass, however, in that high soil temperature yielded optimum root development while low soil temperature favored maximum root growth in the latter.

TABLE VII

DRY AND ASH WEIGHT OF VARIOUS PARTS OF HEMP PLANTS (B), AGE 106 DAYS. TOTAL ABSOLUTE DRY WEIGHT AND TOTAL WEIGHT OF ASH IN ENTIRE PLANT = 100 PER CENT., RESPECTIVELY

TEMPERATURE SERIES	MEAN DRY WT. PER PLANT		DRY WT. PERCENTAGE OF DRY WT. OF ENTIRE PLANT		MEAN ASH WT. PER PLANT		ASH PERCENTAGE OF ASH WT. OF ENTIRE PLANT	
	♂	♀	♂	♀	♂	♀	♂	♀
	gm.	*gm.*	%	%	*mg.*	*mg.*	%	%
LEAVES								
H/H	0.56	1.22	9.2	17.4	78.2	150.0	17.3	31.7
H/L	0.53	1.49	12.1	20.6	50.3	139.9	20.5	28.9
L/H	3.04	1.86	21.9	17.8	224.3	190.3	28.0	29.6
L/L	2.20	2.22	26.6	21.8	161.0	242.8	34.2	42.8
UPPER STEM								
H/H	1.19	1.32	19.0	18.8	102.9	56.2	22.8	11.9
H/L	0.83	1.18	19.0	16.2	67.0	81.2	27.2	16.9
L/H	1.99	1.65	14.4	15.8	108.1	64.3	13.4	10.0
L/L	1.67	1.78	20.1	17.5	116.3	79.0	24.8	13.9
BASAL STEM								
H/H	3.01	2.91	48.0	41.5	97.1	81.9	17.5	17.3
H/L	1.71	2.47	39.1	34.0	37.0	58.9	15.1	12.2
L/H	5.54	4.53	40.0	43.3	138.0	119.9	17.2	18.7
L/L	2.90	3.91	34.9	38.4	69.3	112.7	14.7	19.9
ENTIRE TOP								
H/H	4.76	5.44	76.2	77.7	260.2	288.1	57.6	60.9
H/L	3.07	5.13	70.2	70.8	154.3	279.4	62.8	58.0
L/H	10.56	8.04	76.3	76.9	470.4	374.5	58.6	58.3
L/L	6.78	7.90	81.6	77.7	346.6	434.5	73.7	76.6
ENTIRE ROOT								
H/H	1.51	1.58	23.8	22.3	192.1	186.2	42.4	39.1
H/L	1.30	2.12	29.8	29.2	90.6	202.4	37.2	42.0
L/H	3.31	2.42	23.7	23.1	333.3	269.1	41.4	41.7
L/L	1.54	2.26	18.4	22.3	123.5	133.0	26.3	23.4
ENTIRE PLANT								
H/H	6.27	7.03	....	....	452.3	474.3	....	....
H/L	4.37	7.25	....	....	244.9	481.8	....	....
L/H	13.87	10.47	....	....	803.7	643.6	....	....
L/L	8.32	10.16	....	....	470.1	567.5	....	....

Water requirement by the two low shoot temperature series (L/H and L/L) was less than half that of the H/H and H/L series (table VI) which would indicate a negative or at least no correlation between rate of water absorption and anabolic efficiency. Carbohydrate synthesis has been found to be high at low temperatures in other plants as well (**18, 19, 20**). Great variation in response to temperature occurs among plants of different species. The sunflower (**7, 10**), in contrast to hemp, shows maximum vegetative development when subjected to high air temperature. It can, therefore, be regarded as a heat-loving plant, whereas hemp shows more luxuriant vegetative development at low air and high root temperature.

On the basis of the foregoing data, high air temperature was found to abbreviate the plant life span by accelerated vegetative development with relatively early anthesis, and senescence. While leaf number and area of the high air temperature plants were small, water content and ash weight of leaves were high. The water requirement per unit dry weight more than doubled at high as compared with low air temperature. Staminate flowers began blossoming two weeks earlier than pistillate flowers in the same series.

Conversely, low air temperature tended to prolong the vegetative phase of growth about two weeks and favored production of stem and leaf tissue. There was an increase in absolute and ash weight of the stem and of the entire plant but the percentage of ash in the entire plant was decreased by low as compared with high air temperatures. Low air temperature favors simultaneous anthesis in the two sexes and depresses the percentage of staminate flowers in long day. Short day at anthesis tended to reduce the preponderance of staminate flowers at low air temperatures. Grisko and his associates (**9**) note that short-day treatment induces a tendency in the flowers of the two sexes in hemp to become hermaphroditic.

High root temperature tends to increase the total water absorption and the total number of leaves produced per plant. The absolute amount and percentage of ash in the roots are likewise increased. Optimum conditions for vegetative development in terms of dry weight gain were found in the L/H series and for early flowering in the H/H series. Conditions were least conducive to vegetative growth in the H/L, while latest flowering occurred in the L/L series.

Female plants absorbed more water when root and shoot developed at the same temperature while male plants showed greater aggregate water absorption in those series in which there was a temperature differential between root and shoot. The male plants averaged 14 centimeters taller than the females in all series considered together and the individual male plants were taller throughout than the female plants within the same series. Similarly the male plants developed the greater number of nodes at all four temperature combinations. The female plants, on the whole, displayed greater root development than the male plants, surpassing males in root fresh weight in every series. In dry weight of the root, the distinction was not as sharp. The median date of flowering was 11 days earlier on the average for male than for female plants in the four series. Lilienstern and his associates (**15**) found higher photosynthetic rate in male hemp plants prior to flower bud formation while in the female plants greater photosynthetic activity occurred subsequent to flowering. On the basis of the original sex expression of a given set of plants under long day conditions of 16 hours, shift from long to short day of eight hours at anthesis favors a transition to phenological maleness. No such sex reversal or abnormalities of sex expression occurred when the plants were shifted from a 16-hour to a $12\frac{1}{2}$-hour day length at time of flowering.

Summary

The development of common hemp, *Cannabis sativa,* grown in the greenhouse in pure quartz gravel cultures, was traced from germination to maturity under four different temperature conditions as follows:

1. Shoot and root both at high temperature (30° C.), series H/H.
2. Shoot at high temperature (30° C.) and root at low temperature (15° C.), series H/L.
3. Shoot at low temperature (15° C.) and root at high temperature (30° C.), series L/H.
4. Shoot and root both at low temperature (15° C.), series L/L.

A marked decrease in water consumption at or immediately after anthesis followed by a subsequent rise was noted in both staminate and pistillate plants of all series. Marked sex reversal from female to male was noted in the two series L/H and L/L subjected to transition from long to short day at anthesis.

Other significant responses were:

1. H/H series: (a) Maximum stem elongation; (b) largest number of nodes produced; (c) earliest blossoming and seed formation; (d) a preponderance of male flowers; (e) lowest aggregate leaf area of the four series; (f) greatest number of leaf abscissions; (g) highest absolute water consumption during growth cycle.
2. H/L series: (a) Lowest aggregate fresh, dry and ash weights; (b) more male than female flowers; (c) highest percentage dry weight in basal stem.
3. L/H series: (a) Largest stem diameter; (b) largest individual leaves; (c) highest aggregate fresh and absolute dry weight.
4. L/L series: (a) Greatest total leaf area; (b) smallest water consumption per unit leaf area; (c) highest percentage of water content in the roots; (d) latest blossoming of the four series; (e) preponderance of pistillate, or female, flowers.

Though high soil and air temperature (30° C.) favors maximal elongation and uniformity of stem thickness, the foregoing data indicate that the aggregate dry weight yield of hemp is approximately doubled by a combination of cool air (15° C.) and warm substrate (30° C.). The data also indicate the great importance of the edaphic as opposed to air temperature in the structural and nutritional ontogeny of hemp.

MISSOURI VALLEY COLLEGE
MARSHALL, MISSOURI

LITERATURE CITED

1. ARNDT, C. H. Water absorption in the cotton plant as affected by soil and water temperature. Plant Physiol. **12**: 703–720. 1937.
2. CANNON, W. A. Soil temperature and plant growth. Plant World **20**: 361–363. 1917.
3. CARROLL, J. C. Effects of drought, temperature and nitrogen on turf grasses. Plant Physiol. **18**: 19–36. 1943.
4. CLEMENTS, F. E., and MARTIN, E. V. Effects of soil temperature on transpiration in *Helianthus annuus*. Plant Physiol. **9**: 619–630. 1934.
5. DARROW, R. A. Effects of soil-temperature, pH, and nitrogen on the development of *Poa pratensis*. Bot. Gaz. **101**: 109–127. 1939.
6. DEMIDENKO, T. T., and BARINOVA, R. A. Influence of soil temperature on the uptake of nutrient elements by spring wheat. C. R. Acad. Sci. URSS **26**: 403–405. 1940.
7. ————, and GOLLE, V. P. Influence of soil temperature on the yield and uptake of nutrient elements by the sunflower. C. R. Acad. Sci. URSS **25**: 324–327. 1939.
8. DÖRING, B. Die Temperatur-abhänigkeit der Wasseraufnahme und ihre ecologische Bedeutung. Zeitschr. Bot. **28**: 305–383. 1935.
9. GRISKO, N, N., PANCENKO, P. F., and MALUSA, K. V. Genetics and breeding of hemp. Vsesojuznyi Naucno-Issledovatel'skii Institut Konopli, Trudy (State Hemp Research Institute, Transactions) Moscow and Leningrad. 1937.
10. HESSELTINE, V. J. Effects of contrasted root and shoot temperatures on growth of sunflower. M.S. thesis, State University of Iowa. 1941.
11. JONES, L. H. Relation of soil temperature to chlorosis of gardenia. Jour. Agr. Res. **57**: 611–621. 1938.
12. KRAMER, P. J. Effects of soil temperature on the absorption of water by plants. Science n.s. **79**: 371–372. 1934.
13. ————. Root resistance as a cause of decreased water absorption by plants at low temperatures. Plant Physiol. **15**: 63–79. 1940.
14. ————. Species differences with respect to water absorption at low soil temperatures. Amer. Jour. Bot. **29**: 828–832. 1942.
15. LILIENSTERN, M. F., TCHIJEVSKAJA, Z. A., and WALTHER, O. A. A comparative study of the photosynthetic activity in male and female hemp plants. Acta Inst. Bot. Acad. Sci. URSS, Bot. Exp. 4 ser., no. **5**: 72–87. 1941.
16. MAXIMOV, N. A. The plant in relation to water. Pp. 83–87. London. 1929.
17. MOLLIARD, M. De l'influence de la temperature sur la determination du sexe. C. R. Acad. Sci. (Paris) **76**: 669. 1898.

18. Morozov, A. S. Effect of temperature upon the reversible activity of invertase in forage grasses as dependent on their cold and heat resistance. C. R. Acad. Sci. URSS **23**: 949–951. 1939.
19. Nightingale, G. T. Effect of temperature on metabolism in tomato. Bot. Gaz. **95**: 35–58. 1933.
20. Plitt, T. M. Some photoperiodic and temperature responses of the radish. Plant Physiol. **7**: 337–338. 1932.
21. Sachs, J. Beiträge zur Lehre von der Transpiration der Gewächse. Bot. Zeit. **18**: 121–126. 1860.
22. Withrow, R. B., and Biebel, J. P. Nutrient solution methods of greenhouse crop production. Purdue Univ. Agr. Exp. Sta. Circular no. 232. 1938.
23. Wort, D. J. Soil temperature and growth of Marquis wheat. Plant Physiol. **15**: 335–343. 1940.